

SIMPLE AND COMPLEX COGNITIVE FUNCTIONS UNDER EXERTIONAL HEAT STRESS

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UTICAJ TOPLOTNOG STRESA I FIZIČKE AKTIVNOSTI NA KOGNITIVNE SPOSOBNOSTI

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Received / Priljubljen: 12. 06. 2014.

Accepted / Prihvaćen: 12. 07. 2014.

ABSTRACT

Heat stress is a significant problem in the military services. This study investigated the effects of exertional heat stress on cognitive performance.

Forty unacclimated male soldiers performed exertional heat stress tests in cool (20 °C) and hot environments (40 °C). Cognitive performance was assessed using a computerized battery before and immediately after tests. Physical strain in cool conditions induced mild but significant deficits in accuracy in complex tests. The number of correct answers in the Matching to Sample Visual Search was reduced (92,18% correct answers before vs. 88,64 after; $p < 0,05$) and also in the spatial part of the Pattern and Spatial Recognition Memory Test (85,25 vs. 8,75%; $p < 0,05$). These decreases were more pronounced in hot conditions (92,38 vs. 84,31% in before and 84,21 vs. 73,42% in the latter test; $ps < 0,01$ and $< 0,001$, respectively). Exertional heat stress also impaired more simple cognitive functions. A significant decrease in accuracy (95,74 vs. 93,89%) and an increase in reaction time (300,32 vs. 315,00 ms) was observed in the Reaction Time test.

Strenuous physical activity in a hot environment induces mild cognitive deficits, especially in more complex tasks.

SAŽETAK

Toplotni stres predstavlja značajan problem u vojnoj službi. U ovom istraživanju se ispituje uticaj toplotnog stresa i fizičke aktivnosti na kognitivne sposobnosti.

40 neaklimatizovanih vojnika muškog pola podvrgnuto je testu toplotnog stresa i fizičkog napora u termoneutralnoj (20 °C) i toploj sredini (40 °C). Kognitivne funkcije su ispitivane kompjuterizovanom baterijom neposredno pre i nakon testa. U termoneutralnim uslovima, fizički napor je izazvao blagi pad preciznosti pri rešavanju složenih zadataka u testu Matching to Sample Visual Search (92,18% vs. 88,64; $p < 0,05$), i prostornoj komponenti testa Pattern and Spatial Recognition Memory (85,25 vs. 8,75%; $p < 0,05$). Pad preciznosti je naglašeniji u toplim uslovima (92,38 vs. 84,31%; $p < 0,01$, odnosno 84,21 vs. 73,42%; $p < 0,001$), gde je, osim toga, došlo i do oštećenja jednostavnijih kognitivnih funkcija: u testu Reaction Time zabeležen je pad preciznosti (95,74 vs. 93,89%), kao i produženje vremena reakcije (300,32 vs. 315,00 ms).

Intenzivan fizički napor u toploj sredini dovodi do blagih kognitivnih deficita, pogotovo pri vršenju složenih zadataka.

ABBREVIATIONS

CANTAB - Computerized Cognitive Attention Battery
EHS - Exertional Heat Stress
EHST - Exertional Heat Stress Test

HR - Heart Rate
Tty - Tympanic temperature
WBGT - Wet Bulb Globe Thermometer

INTRODUCTION

Heat stress is a significant problem in the military services. Common preventive measures (e.g., restriction of physical activity, removal of clothing and moving into shade) are often impossible to achieve. Additional disadvantages include the burden of heavy equipment, ballistic

vests, and other heavy items that must be worn during training and regular activities, and impermeable protective suits, which may inhibit evaporative cooling. Heat stress can impair physical and mental performance (1,2). Studies of cognitive performance under hot conditions are



difficult to evaluate because of variations in methodological design, exposure duration, skills and acclimation level. Human tolerance to heat stress also depends on fitness levels. Individuals with higher aerobic capacity show better adaptation to the combination of physical activity and hot environments (3).

Computerized batteries are applied to minimize bias in assessments of cognitive performance during physical exertion and/or heat stress (4, 5). CANTAB (computerized Cambridge Neuropsychological Test Automated Batteries) is a set of neuropsychological tests that are specifically designed for comparative assessments of cognition. The tests are graded in nature, with standardized feedback and a detailed recording of accuracy and speed.

Our study investigated the effects of strenuous physical activity in combination with a hot environment on cognitive performance in young fit male soldiers using computerized test batteries.

SUBJECTS AND METHODS

The participants were 40 male soldiers, aged $20 \pm 0,9$ years, with similar anthropometric and ergometric characteristics (Table 1). Subjects signed an informed consent form after a short briefing on the nature and purpose of the experiment. The Ethical Committee of the Military Medical Academy approved the experimental protocol. The procedures corresponded to international standards of thermal strain evaluation (6, 7). The subjects were randomly divided in two equal groups. The experimental group (H group) performed the exertional heat stress test (EHST) in a hot environment (40°C , 29°C WBGT), and the control group (C group) performed the same test in a cool environment (20°C , 16°C WBGT). Trials were conducted in a climatic chamber in the Military Medical Academy, Institute of Hygiene, Department of Physiological Strain, during November and December 2011. Parameters of heat stress (tympanic temperatures and heart rates) were automatically monitored and recorded in real-time using a physiological data monitoring system (MP150SKT100C, BIOPAC Systems Inc., USA), and the Q4500 Exercise Test Monitor (Quinton Instruments, USA) respectively. The test and measurement protocols were described in detail in our previous studies (8, 9). Tests were limited to 90 minutes because of the temperature conditions and level of

Table 1. Anthropometric and ergometric parameters in both investigated groups

	H	C	<i>p</i> (H vs. C)
Body height (cm)	180,63 ± 5,71	179,55 ± 4,57	0,595081
Body weight (kg)	74,85 ± 9,66	78,13 ± 5,32	0,656162
Body Mass Index (kg/m ²)	22,9 ± 2,62	24,29 ± 1,95	0,803931
Percentage of body fat (%)	16,86 ± 3,62	17,06 ± 4,47	0,710612
VO _{2max} (ml/min/kg)	59,55 ± 10,64	56,60 ± 5,91	0,235727

VO_{2max} - Maximal oxygen consumption

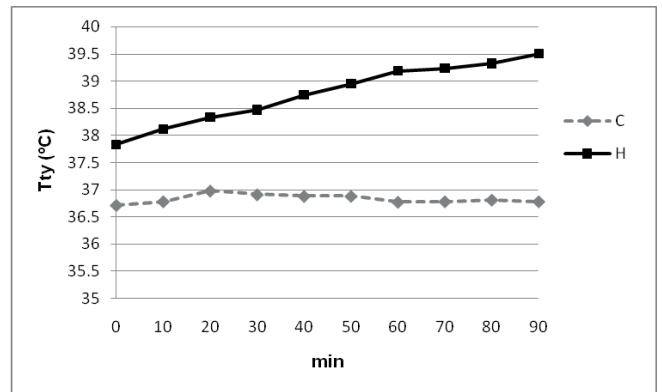


Figure 1. Average tympanic temperatures during the tests in both investigated groups

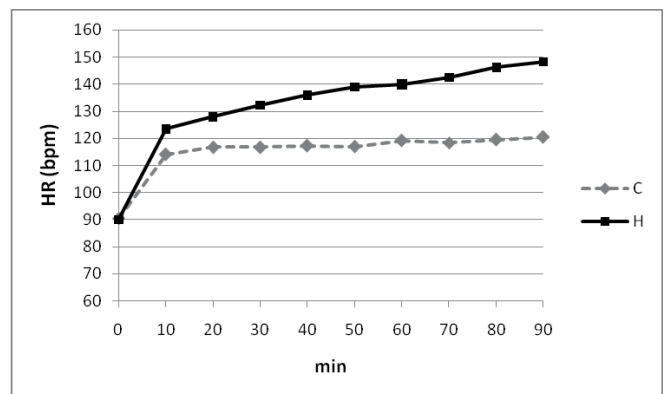


Figure 2. Average heart rates during the tests in both investigated groups

physical exertion. The following criteria were used for early termination: Tty $39,5^\circ\text{C}$, HR 190 bpm, or intolerable subjective discomfort. Cognitive performance was assessed using CANTAB, version 2,0, which consisted of 5 different tests that measure selective, divided, and sustained attention, information processing, working memory and recognition (10). Tests were administered using a computer with a touch-sensitive screen, and a response key was used for reaction timing. Cognitive examinations were administered to each soldier before and immediately after EHST, and each examination included the following tests: Motor Screening (MOT), Reaction Time (RTI), Matching to Sample Visual Search (MTS), and Pattern and Spatial Recognition Memory, which includes visual and spatial components (PSRp and PSRs). Accuracy (percentage of correct answers or number of errors) and speed in ms (reaction time, movement time, or attention time) were recorded for each test.

The Statistical Package for the Social Sciences (SPSS 20.0) was used to perform all statistical tests. Continuous variables are presented as means ± standard deviation. Normal distribution was tested using the Kolmogorov-Smirnov test. Differences between performances before and after EHST were tested using repeated measures *t*-test. Significance was accepted at $p < 0,05$.



Table 2. Cognitive performance in both investigated groups

Test	Parameter	H		C	
		Before	After	Before	After
MOT	Latention (ms)	525,00 ±60,88	624,37 ±197,10	560,00 ±99,32	625,15 ±146,67
	Errors (N)	27,00 ±7,17	26,42 ±8,19	29,75 ±13,52	25,35 ±11,76
RTI	Correct answers (%)	95,74 ±3,52	93,89 ±3,43 *	96,77 ±3,59	96,82 ±3,04
	Reaction time (ms)	300,32 ±31,53	315,00 ±33,77 *	308,70 ±50,15	308,9 ±35,52
	Movement time (ms)	367,42 ±102,95	373,21 ±117,67	400,20 ±112,37	394,25 ±128,15
MTS	Correct answers (%)	92,38 ±4,90	84,31 ±9,51 **	92,18 ±5,14	88,64 ±6,95 *
	Latention (ms)	1564,47 ±507,41	1694,89 ±529,68	1604,80 ±526,77	1579 ±522,37
PSRp	Correct answers (%)	90,56 ±5,71	87,94 ±9,70	93,54 ±5,14	90,98 ±7,41
	Latention (ms)	1436,37 ±287,91	1371,42 ±312,63	1380,80 ±262,08	1325,75 ±254,29
PSRs	Correct answers (%)	84,21 ±8,54	73,42 ±10,01 ***	85,25 ±7,52	78,75 ±15,55 *
	Latention (ms)	1558,79 ±428,23	1653,79 ±444,71	1524,05 ±342,89	1481,65 ±380,81

* p<0,05 after vs. before
 ** p<0,01 after vs. before
 *** p<0,001 after vs. before

RESULTS

Table 1 shows the anthropometric and ergometric characteristics of the subjects. Both groups were similar in all investigated features. No soldier showed any symptoms of heat exhaustion or other severe heat illness during or after EHST. All participants in the C group completed the tests, but 3 soldiers in the H group terminated tests between 60 and 85 minutes because of subjective intolerable strain or the reaching of the Tty limit. Figure 1 displays comparable reviews of Tty values during EHST. The mean Tty was significantly higher in the H group at the end of EHST (i.e., 90th minute) (39,5±0,16 °C vs. 36,78±0,11 °C in the C group; p=0,0006). The total increase in Tty values (average difference between Tty at the beginning and end of EHST) was also significantly higher in the H group (1,56±0,26 °C vs. 0,07±0,03 °C in the C group; p=0,009). Figure 2 displays comparable reviews of HR values during EHST. Mean HR at the end of EHST was significantly higher in the H group (148,90±5,90 vs. 120,50±7,60 bpm; p=0,0000). The limit of 180 bpm was never reached, and the maximum recorded heart rate was 165 bpm. Table 2 summarises performance task means. There was a significant decrease in the percentage of correct answers in the C group in the MTS test after EHST (88,64±6,95 after EHST vs. 92,18±5,14% before; p=0,038) and the PSRs test (78,75±15,55 vs. 85,25±7,52%; p=0,037). Decreases in the accuracy of both of these tests were more

significant in the H group (MTS 84,31±9,51 vs. 92,38±4,90% and PSRs 73,42±10,01 vs. 84,21±8,54%; ps=0,002 and 0,0006, respectively). There was also a statistically significant decrease in performance in the RTI test in the H group. A decrease in the percentage of correct answers (93,89±3,43 vs. 95,74±3,52%; p=0,41) was accompanied by a significant increase in reaction time (315,00±33,77 vs. 300,32±31,53 ms; p=0,048). There were no significant differences between responses for latency or number of errors before and after EHST in other tests, regardless of ambient conditions.

DISCUSSION

Heat strain impairs working efficiency and induces cognitive deficits. These abilities are particularly important in military services, where a dose-dependent relationship between heat stress and the number of errors in helicopter pilots is well established in laboratory and terrain conditions (11,12). Banta and Braun also found that Navy helicopter pilots wearing individual cooling suits during the Gulf war to mitigate the detrimental effect of heat stress on cognition showed improved vigilance and accuracy (13). The possible beneficial effects of microclimate cooling were also of interest in the Army of Serbia. Jovanovic et al. demonstrated the efficiency of individual microclimate cooling systems based on phase-change materials, which alleviated the physical



exertion caused by uncompensable heat stress (8, 9). They investigated male soldiers who performed EHST wearing impermeable protective suits and various types of microclimate cooling vests in a simulated environment (climatic chamber) and external conditions. They concluded that the use of cooling vests under protective suits during physical activity in hot conditions reduced sweating and alleviated heat stress, which was measured by increased core temperature and heart rate values. These cooling vest-induced physiological changes directly improved heat tolerance and hydration state, decreased the risk of heat illness, and extended the duration of soldiers' exposure to hot conditions. Dehydration itself profoundly influences cognitive performance (14), and the use of microclimate cooling systems may represent a promising solution to maintain vigilance and accuracy in soldiers exposed to heat stress.

Our results indicate that physical strain itself induced mild cognitive deficits, which was shown in the increased number of errors during the performance of complex tasks (i.e., MTS and the spatial part of the PSR test). These tests are designed to investigate working memory and sustained attention, and the latter test also investigates spatial orientation, which is a very specific and advanced function that is highly important in military services. The generally good performance of our soldiers in cool conditions is consistent with the results reported by other authors, who found that an acute boost of exercise may improve cognition (15). Mild deficits in our investigation may be caused by the longer duration and more strenuous physical activity compared to the study cited above.

The combination of the same intensity of physical strain and heat stress in our investigation led to more pronounced cognitive impairments in the same complex test, but it also imposed additional effect on attention, which are tested in the RTI. Soldiers in hot conditions showed a significant decrease in accuracy and a significant delay in reaction time in the RTI. The only function that was unaffected in this test was movement time. This mild cognitive deficit can likely be attributed to heat stress.

Hancock and Vasmatazidis stated in their review (16) that there are major difficulties in the interpretation of data on the influence of heat stress on cognitive functions. These difficulties are the consequences of various testing procedures, task demands and categorisation, duration of heat exposure, and subjects' skills and experience. These authors suggest that simple mental tasks show little, if any, decrements following heat exposure, and these tasks are frequently enhanced during brief exposures. However, substantial heat stress (30-33 °C WBGT) may lead to impairments in the performance of more complex tasks. The obtained results are consistent with the high WBGT (29 °C) in our trial.

Most of our subjects who performed tests in a hot environment suffered intensive physical strain, which was recorded by the high values of core temperature (up to 39,5 °C) and heart rates for a substantial time. However, these subjects did not show signs of serious cognitive deficits. Their relative resistance to heat exertion may be attributed to their high aero-

bic capacity. This hypothesis is supported by the facts that some aspects of heat stress-induced cognitive impairment are explained by cerebral changes (17,18), blood oxidative stress (19), and acute inflammatory reactions (20,21). Several investigations (22,23) confirmed that regular aerobic activity significantly induces beneficial adaptive effects on oxidative stress responses and inflammation parameters to acute exhausting endurance exercise in the heat, and our results may be interpreted from this point of view.

CONCLUSIONS

This study demonstrated the effects of strenuous physical activity in a hot environment on physiological parameters, which showed higher values of tympanic temperature and heart rate compared to cool conditions. This physiological heat stress enhanced the cognitive impairment caused by physical exertion itself. Performance deficits in a cool condition were mild and present only in complex tasks, but simpler tasks were relatively unaffected. Performance deficits in hot conditions were more pronounced and present in both complex and simpler tasks, such as reaction time.

Acknowledgment

This investigation was performed as a part of the MNTR 2011-2014, project TR 34034, which was financially supported by Ministry of Education, Science and Technological Development, Republic of Serbia.

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